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MP-1

SAMPLING PROCEDURES, DESIGNS AND PROJECTED COSTS

FISH PASSAGE PROJECTS EFFECTIVENESS MONITORING

(Culverts, Bridges, Fishways, Logjams, Dam removal)

Prepared by

Washington Salmon Recovery Funding Board

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This is a draft document and is available for public review and critique. All contents are subject to change.

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ORGANIZATION

Fish passage improvements are the most popular kind of habitat restoration project. They have accounted for 35% of all SRFB projects and 36% of the funding. They have the greatest potential to create dramatic improvements in fish production in a very short time (1-5 years). This document details the monitoring procedures and protocols necessary to document and report the effectiveness of these projects. Projects designed to restore instream passage treated in this protocol include:

- **Bridge projects**
- **Culvert improvements**
- **Dam removals**
- **Debris removals**
- **Diversion dam passage**
- **Fishway construction**
- **Weirs**
- **Water management projects**

The procedures and protocols are intended to assist project applicants when planning a salmon recovery project, and to assist the SRFB in evaluating which projects are most valuable and effective. All projects selected for effectiveness monitoring must have a written monitoring plan.

The goal of fish passage projects is to restore passage to areas fully or partially blocked by natural impediments or man made impediments, and thereby restore the historic range of salmon and increase the overall watershed productivity and production.

MONITORING GOAL

Determine whether fish passage projects are effective in restoring upstream passage to targeted species of salmon and trout.

QUESTIONS ANSWERED

Level 1. Have the engineered fish passage projects continued to meet design criteria post-project for at least five years?

Level 3 Have fish passage projects as an aggregate demonstrated increased abundance of target species of salmonids post-project within five years?

MONITORING DESIGN

For all fish passage projects, the Level 1 outcome is to meet the approved project design criteria for fish passage. An appropriate sample taken from all fish passage projects should be tested for effectiveness in meeting design criteria.

It is desirable to also evaluate the Level 3 effectiveness of projects in terms of improved fish presence or production upstream of the barrier. For any of the fish passage projects where restoring or improving upstream passage is the desire, one of two conditions exist.

Either:

- There are currently no salmon of the targeted species utilizing the area upstream of the barrier;

Or;

- The targeted species is present, but considered to be in reduced numbers due to the blockage.

About half of the annual fish passage projects fall into each of these categories.

Each of the projects will utilize one impact reach in the proposed project area and a paired downstream control area near the project in an area with similar reach characteristics. In Year 0 (one year prior to barrier removal), “Before” sampling of the project control and impact reaches is completed. After the restoration project has been completed, the control and impact areas for each of the projects will be sampled for three years (Years 1, 3 and 5) for changes in the fish abundance indicators.

The Board will employ a before and after control impact (BACI) experimental design to test for changes associated with barrier removal (Stewart-Oaten et al. 1986). A BACI design samples the control and impact simultaneously at both locations at designated times before and after the impact has occurred. For this type of restoration, barrier removal would be the impact, a location below the barrier would represent the control and a location upstream of the barrier would represent the impact, that is, the location impacted by the project.

For fish abundance, the BACI design tests for changes upstream of the barrier removal *relative to* the abundance observed at control sites downstream. This type of design is required when external factors (e.g., ocean conditions and harvesting) affect the population abundances at the control sites. The object is to see whether the difference between upstream and downstream abundances has changed as a result of the removal projects.

A paired *t*-test will be used to test for differences between control (downstream) and impact (upstream) sites during the most recent impact year and Year 0. In other words, we first compute the difference between the control and impact and use those values in a paired *t* test. This test assumes that differences between the control and impact sites are only affected by barrier removal and that external influences affect population abundance in the same way at both the control and impact sites. The paired sample *t*-test does not have the same assumptions for normality and equality of variances of the two-sample *t*-test but only requires that the differences are approximately normally distributed. In fact, the paired-sample test is really equivalent to a one-sample *t*-test for a difference from a specified mean value.

To implement the design, we will monitor 15 fish passage projects proposed for funding in 2003, and 15 in 2004. This will provide 30 total projects to test for Level 1 and Level 3 effectiveness. The number of projects proposed for funding in each category will be based upon the calculated sample size needed to obtain statistically significant information in the shortest amount of time. If there are insufficient projects funded in any one year to obtain a proper sample size, then replicates of the design will be used in multiple years until the critical sample size is reached.

The variance associated with impact and control areas will not be known until sampling has occurred in Year 0 of both impact and control areas. After Year 0, a better estimate of the true sample size needed to detect change will be available. Cost estimates and the number of sampling replicates may need to be adjusted at that time.

At the end of the effectiveness monitoring testing, there will be one year of "Before" impact information for all projects for both control and impact areas, and multiple years of "After" impact information for the same control and impact areas for each of the projects.

Depending upon circumstances, the results may also be tested for significance, using a linear regression model of the data points for each of the years sampled and for each of the indicators tested.

Testing for significant trends can begin as early as Year 1. Over time, both replicates will be combined to test for significance. Final sampling may be completed in 2008 for replicate 1 and 2009 for replicate 2.

INDICATORS:

Level 1. **Project design criteria taken from construction blueprints or pre-project plan.** New stream crossing structures and restoration of fish passage at identified fish passage barriers should utilize design criteria provided through WDFW in the Aquatic Habitat Guidelines guidance documents. These guidance documents are based on best available science related to fish passage. Bridges are most likely to achieve natural stream processes when correctly designed rudimentary bridge design criteria appears in "*Fish Passage Design at Road Culverts"* (Bates et al. 2003). Bates et al. (2003) also identifies criteria for culvert size, slope, extent of placement below grade level, and channel bed characteristics within the culvert (no-slope and stream simulation methods) that promote natural channel processes inside crossing structures. Retrofit of existing culverts, where the culvert can't be replaced using more preferred methods, may be designed and evaluated using the hydraulic method. Fishways, which depart the furthest from natural conditions, should be designed and evaluated using "*Draft Fishway Guidelines for Washington State"* (Bates and Wiley, 2000).

Level 3. **Numbers of adult and juvenile salmon in the reach.** Abundance of salmon can be determined using both adult spawner and redd counts and juvenile counts. Both adults and juveniles will be monitored using protocols developed by Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife. Adult estimating procedures are found in Protocol 9. Juvenile estimating procedures are found in Protocols 7 and 8. The least intrusive monitoring protocol should be used whenever possible. Impact areas will be compared to the controls and to controls and impacts on other streams as well. The metrics used will be numbers per square meter for juveniles and number per mile or redds per mile for adults depending upon the target species.

OBJECTIVES

BEFORE PROJECT OBJECTIVE YEAR 0

Level 1. Determine the proper design criteria for meeting best management practices for the fish passage projects.

Level 3. Determine salmon abundance both in the downstream control reach and impact reach upstream of the fish blockage for the sampled projects.

AFTER PROJECT OBJECTIVE YEARS 1, 2, AND 5

Level 1. Determine whether fish passage design criteria are being met at each project sampled.

Level 3 Determine salmon abundance both in the downstream control reach and impact reach upstream of the fish blockage for each project.

NULL HYPOTHESIS

Removal or modification of the upstream fish passage barrier has had no effect upon:

1. Increasing the linear distance available for salmon production (spawning areas and juvenile rearing areas) as measured by the passage design criteria..

2. Increasing the overall abundance of salmon upstream of the project (e.g., “the number of chinook per mile and the number of redds per mile will increase relative to the control sites downstream.”)

DECISION CRITERIA

Level 1. Effective if design criteria are met for 80% of the structures on Year 5 (i.e., no statistical test), and;

Level 3. Effective if a change of 20% or more is detected for salmon abundance of either adults, redds, or juveniles between the calculated difference between the paired impact and control areas by Year 5 at the Alpha =0.05 level.

POST-PROJECT DELIVERABLES

The monitoring entity will deliver to the SRFB on Year 1, 2, and 5:

- A completed copy of all monitoring data in the required format.
- A completed metadata form in the required format.
- Miles of stream available for salmon post project.
- Relative abundance of salmon per mile.
- A statement as to whether Decision Criteria were met as an effective project at Level 1 and Level 3.

SAMPLING

SELECTING SAMPLING REACHES

Impact Areas

Fish passage projects are often larger than other types of restoration projects and may not be measured in its entirety. One stream reach immediately upstream of the project in suitable spawning and rearing habitat will be identified and sampled according to Protocol 1 for each of the projects. The assumption is that fish colonizing new habitat will colonize the area nearest the barrier first.

Control Areas

A paired control reach immediately downstream of each project site should be selected in the same manner as the impact reach for each of the projects.

BEFORE PROJECT SAMPLING

All fish passage projects identified for long term monitoring by the SRFB must have completed pre-project Year 0 monitoring prior to beginning the project.

Year 0 monitoring will consist of:

- Determining the linear distance in miles to the nearest tenth of area to be opened by the passage project.
- Using Protocol #6 determine the design criteria for the fish passage structure.
- Using Protocols #7, 8, or 9, determine the abundance of adult and juvenile salmon in the impact and control areas.

AFTER PROJECT SAMPLING

Upon completion of the fish passage project, Years 1, 2, and 5 monitoring will:

- Using Protocol #6, determine whether the design criteria are met for the fish passage structure.
- Using Protocols #7, 8, or 9, determine the abundance of adult or redds and juvenile salmon in the impact and control areas.

TESTING FOR SIGNIFICANCE

We can create a table resembling the following from the data collected for each of the indicators for Level 1 fish passage design, Level 3 juvenile abundance, and adult abundance.

Table 1. Example table for Level 1 Passage design criteria met (Yes/No) for Replicate 1

	Year 0 2003	Year 1 2004	Year 2 2005	Year 5 2008
	Impact	**Impact**	**Impact**	**Impact**
Proj. 1	**N**	**Y**	**Y**	**N**
Proj. 2	**N**	**Y**	**Y**	**Y**
Proj. 3	**N**	**Y**	**Y**	**Y**
Proj. 4	**N**	**Y**	**Y**	**Y**
Proj. 5	**N**	**Y**	**N**	**N**
Proj. 6	**N**	**Y**	**Y**	**Y**
Proj. 7	**N**	**Y**	**Y**	**N**
Proj. 8	**N**	**Y**	**Y**	**Y**
Proj. 9	**N**	**Y**	**N**	**N**
Proj.10	**N**	**Y**	**Y**	**Y**
Proj. 11	**N**	**Y**	**Y**	**Y**
Proj. 12	**N**	**Y**	**Y**	**N**
Proj. 13	**N**	**Y**	**N**	**N**
Proj. 14	**N**	**Y**	**Y**	**Y**
Proj. 15	**N**	**Y**	**Y**	**Y**
Percent Effective	**0**	**100**	**80**	**60**

Table 2. Example table of hypothetical Replicate 1 juvenile abundance (#/m^2) for steelhead yearlings >90mm for Year 0 (BEFORE) and Year 2 (AFTER).

	BEFORE Year 0 (2003) #/m^2			AFTER Year 2 (2004) #/m^2		
	Impact	**Control**	**Diff. (C-I)**	**Impact**	**Control**	**Diff (C-I)**
Proj. 1	**0.0000**	**0.0123**	**0.0123**	**0.0050**	**0.0177**	**0.0127**
Proj. 2	**0.0166**	**0.0739**	**0.0573**	**0.0171**	**0.0525**	**0.0354**
Proj. 3	**0.0000**	**0.0206**	**0.0206**	**0.0121**	**0.0313**	**0.0192**
Proj. 4	**0.0000**	**0.0402**	**0.0402**	**0.0410**	**0.0411**	**0.0001**
Proj. 5	**0.0206**	**0.0464**	**0.0258**	**0.0190**	**0.0499**	**0.0309**
Proj. 6	**0.0008**	**0.0056**	**0.0048**	**0.0228**	**0.0100**	**-0.0128**
Proj. 7	**0.0113**	**0.0479**	**0.0366**	**0.0400**	**0.0555**	**0.0155**
Proj. 8	**0.0014**	**0.0008**	**-0.0006**	**0.0127**	**0.0076**	**-0.0051**
Proj. 9	**0.0000**	**0.0000**	**0.0000**	**0.0511**	**0.0422**	**-0.0089**
Proj. 10	**0.0019**	**0.0166**	**0.0147**	**0.0040**	**0.0330**	**0.029**
Proj. 11	**0.0092**	**0.0120**	**0.0028**	**0.0253**	**0.0317**	**0.0064**
Proj. 12	**0.0000**	**0.0370**	**0.0370**	**0.0000**	**0.0257**	**0.0257**
Proj. 13	**0.0056**	**0.0110**	**0.0054**	**0.0111**	**0.0195**	**0.0084**
Proj. 14	**0.0000**	**0.1000**	**0.1000**	**0.0003**	**0.1111**	**0.1108**
Proj. 15	**0.0000**	**0.0610**	**0.0610**	**0.0435**	**0.0806**	**0.0371**
Mean	**0.0045**	**0.0324**	**0.0279**	**0.0203**	**0.0406**	**0.0203**
Var.	**0.00005**	**0.0009**	**0.0008**	**0.0003**	**0.0007**	**0.0009**
SD	**0.0068**	**0.0294**	**0.0283**	**0.0166**	**0.0273**	**0.0297**

Statistical Testing For Changes in Juvenile Abundance

The number of juveniles per square meter has been shown to be more descriptive than using either linear measures (#/m) or volume measures (#/m^3).

The data will be tested using a paired *t*-test. The paired *t* test is a very powerful test for detecting change because it eliminates the variability associated with individual sites by comparing each stream to itself, that is, at upstream and downstream locations within the same stream. The impact reach and control reach for each stream are affected by the same local environmental factors and local characteristics in the fish population in contrast with other stream systems with their own unique environmental conditions. In other words, the two observations of the pair are related to each other.

Because the paired *t* test is such a powerful test for detecting differences, very small differences may be statistically significant but not biologically meaningful. For this reason a minimum difference will be defined as a 20% increase in populations at the impact sites. The test will be one-sided for an Alpha=0.05. We use a one-sided test because a significant decrease in salmon abundance after the impact would not be considered significant, that is, the project would not be considered effective. In other words, we are not interested in testing for that outcome. The test will be conducted in Year 1, 2, and 5. If the results are significant in any of those years, the fish passage projects will be considered effective.

Our conclusions are therefore, based upon the differences of the paired scores for the 15 (30 after completing 2 replicates) sampled fish passage projects. Though somewhat confusing, it may be helpful to think of the statistic as the “difference of the differences”. A one-tailed paired-sample *t*-test would test the hypothesis:

H_0 : The mean difference is less than 20% of the difference observed in Year 0.
H_A : The mean difference is greater than 20% of the difference observed in Year 0.

The test statistic is calculated as:

$$t_{n-1} = \frac{\bar{d} - b}{s_{\bar{d}}}$$

where
$\bar{d}$ = mean of the differences for Year 0 and a subsequent year
s_d = variance of the differences
$s_{\bar{d}} = {}^{s_d}\!/\!_{\sqrt{n}}$ = variance mean
b = 20% of the average observed differences between control and impact locations in Year 0, this is the minimum difference we must see
n = number of sites (or site pairs).

STATISTICAL TESTING FOR CHANGES IN ADULT ABUNDANCE

Using hypothetical steelhead redd data from Table 3, the test statistic using the same formula as above would be calculated as

$$t = \frac{3.4 - (0.2 * 8.1)}{4.1/\sqrt{15}} = \frac{3.4 - 1.6}{1.06} = 1.68$$

$$t_{0.05(1),14} = 1.76$$

For this example, 1.68 < 1.76, therefore, we fail to reject the null hypothesis of no change. Note, however, if we had not restricted the amount of change to greater than 20%, the results would have been significant because the *t*-value would be calculated in this way:

$$t = \frac{3.4}{4.1/\sqrt{15}} = \frac{3.4}{1.06} = 3.21$$

Without the restriction on the mean, 3.21 was much greater than the *t*-value required for significant change (*t* = 1.76). In other words, the amount of change observed for these data from Year 0 to Year 1 was significantly different from 0, but the observed difference was not large enough to satisfy our restriction on greater than 20%.

Table 3. Example table of hypothetical data for adult abundance (# redds/mile) for steelhead.

mmmm	Year 0 2003	Year 0 2003	Year 0 2003	Year 1 2005	Year 1 2005	Year 1 2005	Test yr 0 vs. yr 1
	Impact	**Cntrl**	**Diff yr 0**	**Impact**	**Cntrl**	**Diff yr 1**	**Diff yr 0 vs. yr 1**
1	**0**	**9**	**9**	**7**	**10**	**3**	**-6**
2	**4**	**20**	**16**	**8**	**19**	**11**	**-5**
3	**5**	**15**	**10**	**5**	**15**	**10**	**0**
4	**0**	**12**	**12**	**10**	**16**	**6**	**-6**
5	**7**	**16**	**9**	**8**	**14**	**6**	**-3**
6	**4**	**7**	**3**	**5**	**9**	**4**	**1**
7	**2**	**4**	**2**	**4**	**3**	**-1**	**-3**
8	**0**	**0**	**0**	**1**	**1**	**0**	**0**
9	**5**	**15**	**10**	**10**	**17**	**7**	**-3**
10	**0**	**11**	**11**	**12**	**14**	**2**	**-9**
11	**6**	**8**	**2**	**5**	**11**	**6**	**4**
12	**0**	**4**	**4**	**4**	**4**	**0**	**-4**
13	**2**	**10**	**8**	**6**	**9**	**3**	**-5**
14	**0**	**17**	**17**	**11**	**16**	**5**	**-12**
15	**0**	**9**	**9**	**5**	**14**	**9**	**0**
Mean			**8.1**			**4.7**	**3.4**
Variance							**16.7**
SD							**4.1**

DATA MANAGEMENT PROCEDURES

Data will be collected in the field using various hand held data entry devices. Raw data will be kept on file by the project monitoring entity. A copy of all raw data will be provided to the SRFB at the end of the project. Summarized data from pre-project analysis will be maintained in flat files per SRFB prototypes and requirements and downloaded to the PRISM database prior to initiating project construction/action. PRISM database shall contain fields for the following parameters associated with these objectives.

Table 4. Category 1 Fish Passage Projects No Fish Present Pre-Project

Indicator	Metric	Pre impact Year 0	Post impact Year 1	Post impact Year 2	Post impact Year 5
Stream Distance made available	miles	√			
Total distance available pre-impact	miles	√			
Total proportional increase	%	√			
Passage Structure Level 1 effective	Yes/No		√	√	√
Adult salmon abundance Impact	Mean #/mile	√	√	√	√
Adult salmon abundance Control	Mean #/mile	√	√	√	√
Juvenile salmon abundance Impact	Mean #/m^2	√	√	√	√
Juvenile salmon abundance Control	mean #/m^2	√	√	√	√
Level 3 effective	Yes/No		√	√	√

REPORTS

PROGRESS REPORT

A progress report will be presented to the SRFB in writing by the monitoring entity after the sampling season for Year 1 and Year 2.

FINAL REPORT

A final report will be presented to the SRFB in writing by the monitoring entity after the sampling season for Year 5. It shall include:

- Raw data in the required data format.
- Estimates of precision and a power analysis of the data.
- Confidence limits for data. See above.
- Summarized data required for PRISM database.
- Determination whether project met decision criteria for effectiveness.

- Analysis of completeness of data, sources of bias.

Results will be reported to the SRFB during a regular meeting after 1, 2, and 5 years post project. Results will be entered in the PRISM database and will be reported and available over the Interagency Committee for Outdoor Recreation web site and the natural resources data portal.

ESTIMATED COST

Because it is intended that monitoring be an essential part of SRFB habitat restoration work, it is important to be able to have cost estimates to help predict the amount of money necessary to be set aside for monitoring activities.

BEFORE PROJECT COSTS

Level 1 Effectiveness Design Criteria

Part of the overall project design costs and implementation monitoring costs associated with SRFB projects. No new costs.

Level 3B Presence/absence Project Costs

Pre-project costs include a foot reconnaissance survey to determine the location of the blockage, and the linear distance upstream to be benefited by the project. It would also include laying out the randomized sampling reaches and obtaining measures of the wetted usable area within the sampled stream reaches.

A snorkeling, electrofishing, or beach seine survey should be conducted during low flow conditions in the sampled control and impact stream reaches to ascertain that the targeted species is or is not present.

2 days X 2 staff X $225/day = $900 per project

Pre-project costs include a series of weekly foot surveys during the spawning season to look for spawning adults or carcasses. Presence/absence would have to be carried out throughout the spawning cycle or until fish were detected. We can assume that detection of spawners will follow a normal distribution with some spawners detected on the first day of the spawning season and others not detected until the last day or not at all. Therefore, we have assumed that the projects on the average will be sampled half of the spawning season before detecting fish.

4 days X 2 staff X $225/day = $1,800 per project

Total combined cost is $2,700 per project.

Level 3A Salmonid Abundance monitoring costs

To monitor juvenile abundance at least five stream reaches would be sampled using the removal method of population estimation or by snorkeling measured reaches. It is estimated that one reach per day could be effectively sampled or one week of sampling for each project. A minimum of one year sampling should be used, but three years would provide for measuring pre-project variance.

5 days X 3 staff X $225/day X 1 years = $3,375 per project.

For most SRFB fish passage restoration projects, foot surveys are the most appropriate method for detecting adult spawning salmon. Foot surveys are conducted on designated impact and control stream reaches to obtain counts of all live and/or dead salmon, and to record the number of redds observed.

Surveys are conducted repeatedly at intervals of less than seven days during the spawning season for the target species. Weather conditions, water clarity, and number of redds are also recorded.

Carcass sampling should be conducted as part of any adult spawner survey in order to obtain an accurate estimate of the total abundance of males and females in the impact area. Carcass surveys consist of counting dead salmon and collecting information on gender, hatchery origin, and age if needed. Carcass counts should be conducted on a weekly basis throughout the sampling period along with the ground counts of redds. For steelhead, bull trout, and cutthroat, carcass counts will not be applicable.

12 days X 2 staff X $225/day X 1 years = $5,400 per project.

Total combined costs = $7,625

AFTER PROJECT SURVEY COSTS

Level 1 Effectiveness Design Criteria

In order to test the effectiveness of the design, the project site would be visited once during low flow and once during high flow on Year 1, 2, and 5.

2 days X 2 staff X $225/day X 3 years = $2,700 per project.

In order to compare presence/absence costs with monitoring that would measure the overall abundance of juveniles, juvenile migrants or adults, the following cost estimates have been developed.

Level 3B Snorkeling/Electrofishing/Beach Seine and Adult Spawner/Carcass Counts

Post-project costs include a snorkeling, electrofishing, or beach seine survey during low flow conditions in the sampled control and impact stream reaches 1, 2, and 5 years after the project to ascertain that the targeted species is now present in the impacted area and the distance utilized.

1 day X 2 staff X $225/day X 3 years = $1,350 per project.

Pre-project costs include a series of weekly foot surveys during the spawning season to look for spawning adults or carcasses. Presence/absence would have to be carried out throughout the spawning cycle or until fish were detected.

4 days X 2 staff X $225/day X 3 years = $5,400 per project

Level 3A Salmonid Abundance monitoring costs

Monitoring Juvenile Abundance

Year 1, 3, 5, and 10 juvenile sampling should be used,.

$3,375 X 4 years = **$13,500**.

Adult Abundance using Spawner Counts/ Redd Counts

For most SRFB fish passage restoration projects, foot surveys are the most appropriate method for detecting adult spawning salmon. Foot surveys are conducted on designated stream reaches to obtain counts of all live and/or dead salmon, and to record the number of redds observed.

Surveys are conducted as in pre-project monitoring

$5,400 X 4 years = **$21,600**.

Table 5. Estimated Monitoring Costs per project using Level 3B

Monitoring Level	Indicator	Pre-Project Cost Year 0	Post-Project Cost Year 1,2,5	Total Monitoring Cost
Level 1	Passage Design Criteria	Part of Implementation costs	$2,700	$2,700
Level 3B	Adult Spawner [1]Presence/Absence	$1,800	$5,400	$7,200
Level 3B	Juvenile Presence/Absence	$900	$1,350	$2,200
Level 3A	Juvenile Abundance	$3,375	$13,500	$16,875
Level 3A	Adult Spawner/redd abundance	$5,400	$21,600	$27,000
Total		$11,475	$41,850	$53,275

[1] Costs can be minimized using volunteers

REFERENCES CITED

Bates, K.E., B. Barnard, B. Heiner, P. Klavas, and P. Powers (2003). Fish Passage Design At Road Culverts: A design manual for fish passage at road crossings. Washington Department of Fish and Wildlife. Environmental Engineering Division. Olympia, WA. 49 pages,

Bates, K.E., and Wiley. 2000. Draft fishway guidelines for Washington State. Washington Department of Fish and Wildlife. Environmental Engineering Division. Olympia, WA.

Stewart-Oaten, A., W.W. Murdoch, and K.R. Parker (1986). Ecology. Vol. 67(4) pp. 929-940.